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Agroecological Studies of Beckmannia Syzigachne Populations

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AGROECOLOGICAL STUDIES OF

BECKMANNIA SYZIGACHNE POPULATIONS

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable for meeting the thesis requirement for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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Abstract

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Under the supervision of Dr. Arvid Boe

Germination, forage yield and quality, and inflorescence characteristics were studied in populations of *Beckmannia syzigachne* (Steud.) Fern., a valuable wetland forage species in the northern states. Germination and seedling growth differences among populations of *Beckmannia* from South Dakota, Montana, and Alaska were investigated. Caryopses of these populations produced simultaneously in the greenhouse under uniform growing conditions were subjected to 3 constant (15,20, and 25 C) and 2 alternating (15-30 and 20-30 C) temperature treatments. Alaska caryopses had significantly higher percent germination at the constant temperatures than did South Dakota or Montana caryopses. No significant differences among populations were detected for the 15-30 C treatment. The Alaska population had significantly faster rates of germination and early seedling growth than the other populations. South Dakota and Montana populations are apparently inhibited from germination at constant temperatures by a germination restriction mechanism not exhibited by the Alaska population. *Beckmannia* populations from South Dakota and Montana were studied over a 2-year period for forage yield and quality parameter differences. No significant differences among populations

were detected for forage yield, however differences in forage quality parameters existed between harvest dates and populations when harvested early. Montana populations, which were generally higher in forage quality, produced significantly less stem tissue and higher leaf-to-stem ratios than the South Dakota populations. Inflorescence and spikelet characteristics also differed among 6 populations studied. Populations from Montana and South Dakota contained from 7.5 to 33.8 percent biflowered spikelets. The Alaska population contained no biflowered spikelets. Larger spikelets had a higher probability of containing 2 caryopses than the smaller spikelets. The Alaska population had significantly longer inflorescences which supported more spikelets; however, spikelet bracts and caryopses weights were smaller compared to Montana and South Dakota populations. Variability among populations with respect to germination and inflorescence characteristics suggests ecotypic adaptations of the populations to their respective original collection sites.

High seed production was indicated for all the populations. Stand longevity and persistence will depend on utilization, harvesting regime, and other management inputs. Thus, as a potential cultivated forage species this grass has considerable promise.

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Introduction

In the northern Great Plains there is a need for more efficient utilization of temporary wet areas where cropping with cereal or row crops is unpredictable due to high spring-time moisture conditions. In these areas producers may not want dense, sod-forming, perennial grasses which are long-lived and hard to manage in a short-term rotation schedule with other crops. There is very little known about native wetland grass species that might be utilized in such a situation. Factors that might limit incorporation of such species into a cultivated forage system are (1) complex germination requirements that inhibit rapid and uniform germination, (2) low forage yield potential, (3) low forage quality, and (4) poor seed production. Any one of these factors may limit the success of using native grass species as cultivated forages. Moreover, there is very little research aimed at identifying and evaluating potential new forage species.

Beckmannia syzigachne (Steud.) Fern. is a native, cool-season grass common to wet disturbed areas in the northern United States and Canada. It is present in marshes and is known to rapidly colonize areas that have been vegetatively denuded. It has been widely recognized as a palatable, high quality component of wetland hay.

The objectives of this study were to: (1) describe the germination profile, (2) evaluate the agronomic suitability and forage potential, (3) investigate perenniality and stand longevity, and (4) quantify inflorescence characteristics of *Beckmannia syzigachne* populations.

Literature Review

American sloughgrass [Beckmannia syzigachne (Steud.) Fern.] is the North American native of a bispecies genus that is widespread in the cooler parts of Eurasia and North America. B. syzigachne is common in wet meadows and on shores of lakes and ponds from Alaska south to northern California and throughout the northwest and north central states, and is occasional in the Northeast (Gould and Shaw 1983).

Hoffman et al. (1980) reported low germination percentages for B. syzigachne, obtaining a high of 26% from disseminules that had overwintered dry and were tested under ambient April light and temperature at Vermillion, South Dakota. They also indicated that darkness inhibited germination. Boe and Evans (1981) reported that intact spikelets and caryopses freed from spikelet bracts exhibited poor germination at room temperature and disappointing emergence in greenhouse plantings. Boe and Wynia (1985), using field collected and greenhouse produced spikelets from Montana populations, reported significantly higher germination percentages for Beckmannia utilizing alternating temperature rather than constant temperature regimes. They also concluded that darkness did not inhibit germination and that germination percentages were not significantly different for spikelets or caryopses when an alternating temperature was employed. A fall field germination percentage of 51 was reported for spikelets that had matured and disarticulated from the rachis during the summer (Wynia and Boe 1984).

Thompson and Grime (1983) conducted a survey of herbaceous species from a wide range of habitats to determine their response to diurnal temperature changes. When they categorized plants according to habitat it was apparent that a response to alternating temperatures was most characteristic of wetland species, and to some extent, plants of disturbed ground. They indicated that response to temperature fluctuations may limit species to germination at the most favorable period in the growing season for seedling survival. McWilliams et al. (1968) found that *Amaranthus retroflexus* from northern latitudes had significantly higher germination at lower temperatures than southern populations of the same species. They proposed that the difference in germination response was largely due to a difference in dormancy between populations reflecting an evolutionary divergence related to local environment.

Dix and Smeins (1967) reported that *B. syzigachne* is commonly found in cropland depressions in eastern North Dakota. It is a frequent colonizer of vegetatively denuded wetland soils resulting from mud flat exposure, livestock grazing, or tillage (Walker and Coupland 1968, Stewart and Kantrud 1971, Millar 1973,1976). As early as 1896, Beal recognized *B. syzigachne* as a forage of some prominence west of the Mississippi River. It is palatable to livestock (Hitchcock 1951, Stevens 1963) and is frequently hayed or grazed (Clarke and Tisdale 1945). Looman (1983) stated that *B. syzigachne* is palatable to cattle and horses from early stages of growth until seed maturity. Forage nutritional data (Clarke and Tisdale 1945, National Academy of Science 1971) indicate that *Beckmannia* is high in protein and non-structural carbohydrates. Studies in the USSR (Komarov 1963) indicate that *Beckmannia erucaeformis* (L.) Host is similar to timothy in forage quality, gives satisfactory hay yields, good aftergrowth, and was tolerant of salinity. Wilcox et al. (1915) found *Beckmannia* particularly well-adapted to low, irrigated, alkaline soils in western Nebraska. Annuk (1976) reported average first year forage yields with *B. erucaeformis* in Estonia at 3000-5000 kg/ha. Boe and Wynia (1985) found forage yields of *B. syzigachne* to range from 2000-5000 kg/ha in South Dakota. Several authors (Hitchcock 1951, Moss 1959, and Koyama and Kawano 1964) have pointed out strong morphological similarities between *B. syzigachne* and *B. erucaeformis*, and Hulten (1968) considered them to be synonymous.

One of the key taxonomic features distinguishing *B. syzigachne* from its European counterpart *B. erucaeformis* is the number of florets per spikelet. Floras generally describe *B. syzigachne* and *B. erucaeformis* spikelets as containing one and two florets, respectively (Hitchcock 1951, Harrington 1954, and Cronquist et al. 1977). Wynia and Boe (1983) consistently observed production of biflowered spikelets in *B. syzigachne* populations from Montana and South Dakota grown under greenhouse conditions.

Materials and Methods

Germination study

Caryopses of three different populations of B. syzigachne were utilized in this study. Origins of the populations utilized were: 1) a 1981 Montana field collection from near Outlook, MT (MT-81) (49 degrees north); 2) a 1982 field collection from a pond near Brookings, SD (GP-82) (44 degrees north); and 3) a 1973 field collection from near Fairbanks, AK (AL-73) (65 degrees north). The latter has been released by the Alaska Plant Materials Center and USDA-Soil Conservation Service as the variety `Egan´.

Caryopses from these sources were germinated under an alternating temperature regime (21 C for 16 hours / 7 C for 8 hours) and seedlings were subsequently removed from germination blotters and potted in a 3 soil:1 sand mixture. Seedlings were placed in the greenhouse, watered daily, and fertilized monthly until seed matured. Mature spikelets were bulk-harvested from individual populations and hand-threshed on a rubber rubbing board to free caryopses from spikelet bracts. Caryopses were counted into 20 lots of 25 caryopses, weighed on an analytical balance, and placed on blotters in germination trays within 24 hours of harvest. Germination blotters were divided into three sections, with 25 caryopses of each population per section. Each germination blotter served as a block and four blocks were used for each temperature treatment. Temperature treatments utilized were 3 constant (15,20, and 25 C) and 2 alternating (15-30 and 20-30 C) regimes. Alternating temperature germinators were programmed for an 8 hour high and 16 hour low temperature regime. Caryopses were considered germinated when coleoptiles were visible. Germination counts and seedling plumule lengths were recorded daily for 14 days. Analyses of variance were performed on caryopsis weights and 14 day germination percentages (transformed utilizing arc-sine transformation (Scott et al. 1984)). Germination rate (speed of germination) was computed for each population by block within temperatures according to Maguire´s (1962) formula.

$$\text{Rate} = \frac{\text{number of normal seedlings}}{\text{days to first count}} + \frac{\text{number of normal seedlings}}{\text{days to last count}}$$

Analyses of variance were conducted on the resulting values. Chi-square values were calculated utilizing seedling height frequency data within 3 different classes (0.10-0.50, 0.51-1.00, and >1.00 cm) on day 14. Non-germinated caryopses were placed in the 0.10-0.50 cm class for these analyses.

Seed yield, forage production, and forage quality

In September 1984, a seed yield trial (Trial 1) was planted on nearly level Vienna loam [fine-loamy, mixed Udic Haploborolls] on the SDSU Agronomy farm near Brookings, SD. The trial included the following seed lots: 1) MT-81; 2) GP-82; 3) a

1982 seed increase at Brookings from a 1981 Montana field collection (SD-82); 4) a 1983 field collection from a slough in northeastern Montana (OS-83); and 5) a 1983 field collection from a cropland depression in northeastern South Dakota (ST-83). Seeding rate was 16 kg/ha pure live seed (PLS) / plot, with 4 replications in a randomized complete block design. Spikelets were planted at a depth of 1.3 cm with a 4-row (30-cm row-spacing) belt seeder equipped with double-disk openers and depth bands. Plot size was 1.2 by 6.3 m. Total plot seed yields were harvested on 5 Aug. 1985 with a small plot combine. Harvested seed material was then dried, screened, blown to remove inert matter from spikelets, and weighed. All plots were fertilized with 150 g of 37-7-7 per plot on 16 May 1986. The middle 2 rows of the plots in 3 replications of the trial were harvested for seed yield on 3 July 1986. After drying, spikelets were removed from inflorescences by hand-threshing, screened, blown to remove inert material, and weighed.

Trial 2, planted for forage yield evaluation on 16 Nov. 1984, was adjacent to Trial 1 and utilized the same seed sources, seeding rate, design, and fertilization treatment. Forage yield data for 1985 were obtained from 2 harvests of 1.2 by 1.8 m subplots. Replicated subplots were harvested at different stages of plant development. Harvests 1 and 2 were taken at early boot on 19 June and early head on 2 July, respectively. Subplot forage wet weights were recorded and dry weights determined upon drying at 40 C until constant weight. Fifteen random culms from each sub-plot were separated into leaf, sheath, stem, and inflorescence components.

Dried forage was ground to 2.0 mm for quality analysis. Populations were analyzed for total nitrogen, ether extract (EE), acid detergent fiber (ADF), permanganate lignin, ash, crude fiber (CF), and *in vitro* dry matter disappearance (IVDMD). Total nitrogen was multiplied by 6.25 to determine crude protein (CP) percentage. EE, ADF, lignin, CF, and ash were determined in duplicate as outlined by A.O.A.C. (1984). IVDMD was determined in triplicate by modified Tilley and Terry method (Terry et al. 1978).

Trial 2 was harvested once at early head on 12 June 1986. The 3 subplots per plot were harvested and treated as distinct units as in 1985. Forage was weighed, dried, and analyzed for quality as in 1985. Forage and seed yield and forage quality data were subjected to analyses of variance.

Inflorescence characteristics

Spikelets from 6 populations were utilized in the initial study to examine the occurrence of biflowered spikelets in *Beckmannia syzigachne*. Origins of the populations were: 1) 2 field collections from different locations in Sheridan County, Montana in 1980 and 1981 (MT-80 and MT-81); 2) 2 collections from different sites in Deuel County, South Dakota, taken in 1980 (NDC and DC); 3) 1 collection from Kingsbury County, South Dakota, taken in 1979

(KB); and 4) 1 collection from Brookings County, South Dakota, taken in 1979 (BG). Caryopses from the 6 populations were germinated on blotters utilizing an alternating temperature regime (16 hrs at 7 C / 8 hrs at 21 C). Seedlings were planted in a 3 soil:1 sand mixture in the greenhouse when plumules reached a length of 2.5 to 3.0 cm. Plants were watered daily and fertilized monthly until seed maturity. Mature spikelets were bulk-harvested from each population and a portion of the spikelets were divided into large and small fractions utilizing a screen with 2.6 mm diameter openings. Samples of large, biflowered spikelets and small, uniflowered spikelets were taken from each population and spikelet length and width were measured. Random samples of the bulk population, and large and small spikelet fractions were separated into spikelet bracts (glumes, lemmas, and paleas) and caryopses under a stereo-microscope. The spikelet bract and caryopsis components were then weighed on an analytical balance.

In the second study, 4 Beckmannia populations were utilized to determine the extent of variability in inflorescence characteristics among and within populations. Populations studied were: 1) GP-82; 2) ST-83; 3) MT-81; 4) AL-73. Caryopses of the 4 populations were germinated, seedlings transplanted, and plants cared for as in the first study. Individual inflorescences were randomly selected from plants of each population at seed maturity. Data obtained from 10 inflorescences per population included total spikelet number and inflorescence length. For each population, two random 50-spikelet samples were obtained from 5 inflorescences. These samples were separated into spikelet bract and caryopsis fractions and the respective components were weighed on an analytical balance. Analyses of variance were utilized to determine inflorescence and population differences for bract and caryopsis weights, and differences in inflorescence lengths and spikelet numbers / inflorescence. Regression and chi-square analyses were utilized to depict inflorescence, spikelet, and spikelet component relationships in the Beckmannia populations.

Space-plant nursery study

A nursery of 50 B. syzigachne plants was established in 1983 approximately 2 km north of the SDSU campus at Brookings, SD. Transplants were obtained in the spring from volunteer seedlings near a 2-year-old Beckmannia forage yield trial. Seedlings were extracted from the original site using garden trowels to retain root integrity and diminish transplant shock. Transplants were placed in a space-plant nursery with 1.0 meter spacing between plants. Plants were watered at transplanting to enhance establishment. Nurseries were hand weeded to reduce competition and survival was determined in the spring of 1984 and 1985.

A second nursery of 345 space-plants was established 1 km east of the SDSU campus in May 1985. Transplants were obtained, transplanted, and cared for in the same manner as the first nursery. Numbers of flowering culms were counted and total seed harvests taken in 1985 and 1986. Intact inflorescences were harvested and counted. Spikelets were threshed free and weighed to determine total seed yield for each plant. Sixty plants were harvested in July 1985, based on number of flowering culms, to determine if plants with different numbers of culms would be differentially affected by harvesting. Twenty plants each from 3 classes of plants with culm numbers of 20-30, 40-50, and >51 cut to a 5.0cm stubble in 1985 were evaluated for survival and seed yield in 1986.

Chromosome observations

Plants from 7 Beckmannia populations were grown in the greenhouse from the following Montana, South Dakota, and Alaska seed sources: 1) MT-81, 2) SD-82, 3) NDC, 4) DC, 5) GP-82, 6) KB, and 6) AL-73. Juvenile inflorescences were removed from reproductive culms prior to their emergence from the flag leaf sheath. Inflorescences were fixed in a 3 alcohol: 1 glacial acetic acid for 24 to 48 hours. Final storage was in 70% alcohol under refrigeration. Aceto-carmine smears were made from anthers and temporary slides were sealed with wax for later microscopic observation.

Chromosome counts were made for all populations from pollen mother cells at diakinesis. Photomicrographs of pollen mother cells at most stages of meiosis were taken with a Leitz microscope camera at 1200X.

Results and Discussion

Germination study

Caryopses weights of the 3 Beckmannia syzigachne populations produced in the greenhouse were all significantly different (Table 1). The Montana population (MT-81) had the largest caryopses and the Alaska population (AL-73) had the smallest. Baker (1972) found that seed weight in general decreased with increasing altitude in California. He proposed that a decrease in seed weight with elevation may be a matter of decreasing moisture and temperature stress coupled with decreasing length of growing season. Achene weights from different climatic races of Potentilla glandulosa were found to vary with altitude in California (Clausen and Hiesey 1958). Alpine and coastal races grown in a uniform garden situation at Stanford had 100-achene weights of 9 and 30 mg, respectively. McWilliams et al. (1968) found that seed weight of A. retroflexus was dependent upon ecotype and environment under which seed was produced.

Mean percent germinations of the 3 populations of Beckmannia under selected germination temperature regimes are presented in Table 2. Significant differences occurred among germination percentages of the populations at all temperatures except the 15-30 C. AL-73 had significantly higher percent germination at all constant temperatures (Table 3). Probert et al. (1985) reported differences in dormancy and germination response of Dactylis

Table 1. Mean 25-caryopses weights of three *Beckmannia syzigachne* populations grown in the greenhouse in 1986.

Population	n	Mean 25-caryopses weights
		---------mg---------
MT-81	20	8.8 a
GP-82	20	6.9 b
AL-73	20	4.9 c

Numbers in columns followed by a different letter are significantly different at 0.01 level.

Table 2. Mean germination percentages of three populations of *Beckmannia syzigachne* under five different temperature regimes on the 14th day after planting.

	Temperatures (C)				
Population	15	20	25	15-30	20-30
	%				
GP-82	25a	4a	4a	89a	71a
MT-81	33a	2a	4a	91a	91b
AL-73	81b	72b	86b	90a	90b

Numbers in the same column followed by different letters are significantly different at the 0.01 level.

Table 3. Mean squares and significance levels for percent germination of three *Beckmannia syzigachne* populations under five different temperature regimes on the 14th day after planting.

		Temperatures (C)				
Source	df	15	20	25	15-30	20-30
Pop.	2	1425.6**	580.5**	715.8**	21.5	375.6**
Block	3	61.3	2.0	11.2	63.2	226.4*
Error	6	40.1	7.9	11.3	67.5	29.0

*,** Indicates significance at 0.05 and 0.01 levels, respectively.

glomerata populations under different conditions of temperature and light. McWilliams et al. (1968) stated that variation in percent germination between populations of *A. retroflexus* grown under similar conditions was largely genetic in origin. They concluded that germination response differences were due to differences in dormancy between populations. Thompson (1975), utilizing seed of *Silene dioica* for germination studies, found summer-dormant populations from southern Europe and winter-dormant populations from northern Europe.

AL-73 had a significantly faster germination rate than the other two populations under all temperatures treatments (Tables 4 and 5). Germination rates for MT-81 and GP-82 were not significantly different from each other at 20 and 15-30 C, but were different at 15, 25, and 20-30 C. Germination rate differences between populations within temperatures were generally large (Table 4). Chi-square values of seedling numbers within height classes under different temperatures regimes were also all significantly different (Table 6). The chi-square values indicate that the biggest differences in seedling heights among the 3 populations were under the constant temperature regimes. Alternating temperature treatments exhibited reduced differences between number of seedlings in each height class. Considering the faster germination rates for all three populations under alternating temperature conditions, the seedling heights would tend to be more uniform. Mean seedling numbers within each height class by

Table 4. Mean rate of germination (using Maguire´s formula) of three populations of *Beckmannia syzigachne* under five different temperature regimes.

Population	Temperatures (C) 15	20	25	15-30	20-30
GP-82	0.60 a	0.14 a	0.20 a	3.60 a	3.16 a
MT-81	0.99 b	0.11 a	0.11 b	3.55 a	4.11 b
AL-73	2.51 c	4.89 c	7.65 c	8.79 b	9.22 c

Numbers followed by different letters are significantly different at the 0.01 level.

Table 5. Mean squares with significance levels for germination rates of three *Beckmannia syzigachne* populations under five different temperature regimes.

Source	df	Temperatures 15	20	25	15-30	20-30
Population	2	4.10**	30.30**	74.89**	32.89**	42.52**
Block	3	0.16	0.50	0.09	0.52	1.62*
Error	6	0.06	0.62	0.03	0.22	0.25

*,** Indicate significance at the 0.05 and 0.01 levels, respectively

Table 6. Chi-square values of seedling numbers for three *Beckmannia syzigachne* populations within three height classes grown under different temperature regimes.

	Temperatures (C)				
	15	20	25	15-30	20-30
Chi-square	100.16	169.36	211.57	9.49	37.84
Significance	***	***	***	*	***

*,*** Indicates significance at 0.05 and 0.001 levels, respectively.

population across all temperature treatments are presented in Table 7. AL-73 had more than twice as many seedlings in the tallest height class (>1.0 cm) than MT-81 and GP-82. MT-81 and GP-82 had a majority of their seedlings in the smallest height class (0.10-0.50cm) which can be attributed to their lower total germination at constant temperatures and overall slower rate of germination at all temperatures.

In the past it has been assumed that species have characteristic dormancy mechanisms and germination responses throughout their adaptive range (Harper 1965). However, as wide-spread species are studied, especially at the limits of their range, this assumption is being more frequently challenged. This is the result when the populations of <u>Beckmannia syzigachne</u> from South Dakota and Montana are compared to the population from Alaska. The three populations grown under uniform greenhouse conditions produced caryopses that had very different responses to germinator temperature regimes. This would indicate a genetically controlled resistance to germination under certain temperature regimes in the South Dakota and Montana populations that is lacking in the Alaska population. Spikelets mature and disarticulate from <u>Beckmannia</u> plants in mid to late July in South Dakota and Montana. This time of year in the northern Great Plains is consistently warm with sporadic rainfall events. If disarticulated spikelets were to germinate at this time of year, high seedling mortality would likely result because of high temperatures and a lack of consistent

Table 7. Mean seedling numbers across five temperature treatments in each of three height classes for three *Beckmannia syzigachne* populations on the 14th day after planting.

Population	Height classes in centimeters		
	0.10-0.50	0.51-1.00	>1.00
GP-82	64.4	5.0	30.6
MT-81	59.0	5.0	36.0
AL-73	17.4	8.2	74.4

moisture. However, by germinating only upon receiving moisture under fluctuating temperatures, these populations can restrict their germination to the fall or spring with a higher probability of seedling survival, growth, and subsequent reproduction. Field plantings of Beckmannia in August at Brookings have responded in just such a manner with initial germinations taking place in mid to late September (Wynia and Boe, SDSU, unpublished data). Spikelets mature and disarticulate from Beckmannia plants in mid to late August in Alaska (Stoney Wright, Plant Material Center, Palmer, Alaska, Personal communication). On the average, the first killing frost in Alaska coincides closely with spikelet maturity (Table 8). Therefore, due to early onset of cold temperatures, there would be no advantage to fall germination or to mechanisms that restrict germination during the growing season. The apparent insensitivity of this ecotype to temperature during germination would be desirable for maximizing germination when suitable growing conditions are attained. This strategy would improve chances for plant establishment during the short growing season (Table 8). Amen (1966) speculated that late-maturing species in far northern latitudes may encounter low temperatures which effectively prevent germination and reduce the need for dormancy mechanisms. Rapid germination in the spring would allow northern populations the maximum favorable season for growth and reproduction (Angevine and Chabot 1979). McWilliams et al. (1968) stated that rapid germination and establishment are often selective advantages for

Table 8. Climatic parameters at three locations near original *Beckmannia syzigachne* collection sites.

	South Dakota	Montana	Alaska
Annual Precip.(mm)	507.0	316.0	302.0
Ave. July Temp. (C)	22.1	19.2	15.6
Killing Frost (Fall)	Sept 28	Sept 21	Aug 26
Killing Frost (Spring)	May 15	May 23	May 29
Growing days	136	121	89

Source USDA Agriculture Yearbook 1941 - Climate and Man.

species in northern latitudes. The small caryopsis size of the Alaska population coupled with its speed of germination is contrary to the published literature. Green and Hansen (1969) found that the heavier seed of 5 out of 6 range grasses germinated faster than did the lighter seed. More extensive are studies that show a positive correlation between seed weight and seedling vigor in grasses (Kneebone 1956, Kneebone and Crener 1955, and Lawerence 1957). However, Crouch and VanderKloet (1980) found that seed weight of blueberry populations decreased with increase in latitude and that populations from northern latitudes germinated more rapidly than southern populations of the same species. With increasing latitude there seems to be a greater demand for efficiency in the plant's response to a broader range of temperature cues for initiating germination. Northern populations also must reproduce in a shorter time span while starting with a smaller initial resource base. Thus, the Alaska population of Beckmannia responds by germinating quickly under constant as well as alternating temperature treatments, a trait which makes it well-adapted to northern climates and different from populations adapted to the Great Plains.

Seed yield, forage production, and forage quality

Mean seed yields for the 5 B. syzigachne populations harvested from Trial 1 in 1985 and 1986 are presented in Table 9. No significant differences among populations were detected within

Table 9. Mean seed yields for 5 populations of *Beckmannia syzigachne* harvested in 1985 and 1986.

Population	1985 harvest (Machine)	1986 harvest (Hand)
	---------------kg/ha---------------	
MT-81	424	661
SD-82	370	758
GP-82	418	778
OS-83	277	783
ST-83	361	831
Grand mean	370a	762b

Means followed by a different letter are significantly different at the 0.01 level.

harvest years. Large differences in seed yield between harvest years may have been influenced by harvest method.

No significant differences were observed among populations for dry matter yields within a harvest date (Table 10). Total dry matter yield was highest for the oldest growth stage, as is expected with increased maturity and plant size. Analyses of variance of forage quality indicated significant differences between phenological stages for all parameters and among populations for all parameters with the exception of IVDMD (Table 11). Reductions were observed in CP, IVDMD, and EE between early boot and early head harvests with a simultaneous increase in ADF, CF, and lignin in the 5 populations, indicating a decrease in forage quality with increased maturity (Table 12). White and Wight (1984) reported a decrease in forage quality with increased forage yield in several cool-season grass species. Johnson and Waite (1965) found an inverse linear relationship between lignin percentage and *in vitro* digestibility of 2 grass species. Population OS-83 had significantly higher CP and significantly lower ADF, CF, and lignin than the other populations. It also had the highest IVDMD at both growth stages. Heinrichs and Carson (1956) found significant differences in protein, fat, crude fiber, ash, and lignin among grass species and growth stages. Highly significant differences were observed between growth stages for leaf, stem, and inflorescence dry weights (Table 13). However, differences among populations were only significant for stem and

Table 10. Mean dry matter forage yields for 5 *Beckmannia syzigachne* populations cut at 2 different dates and growth stages in 1985.

Population	Cutting date / Growth stage	
	June 19/Early boot	July 2/Early head
	--------------------kg/ha----------------------	
MT-81	3318	5466
SD-82	3368	5137
GP-82	3888	5890
OS-83	2927	5297
ST-83	3167	6157

Means in the same column not significantly different.

Table 11. Mean squares from analyses of variance of forage quality components of *Beckmannia syzigachne* populations harvested at 2 different growth stages.

Quality Component	Mean Squares Population	Stage	Block
CP	18.18**	169.77**	0.080
ADF	18.34**	82.13**	0.001
IVDMD	33.33	925.19**	17.280
CF	10.15**	67.16**	1.000
EE	.25*	2.18**	0.001
Lignin	14.44**	63.76**	0.450
Ash	1.03**	17.69**	0.060

*,** indicate significant at the 0.05 and 0.01 levels, respectively.

Table 12. Forage quality parameters for 5 populations of <u>Beckmannia</u> <u>syzigachne</u> harvested at 2 different growth stages in 1985.

Population	Stage	Forage Quality Parameters					
		CP	ADF	Lignin	CF	IVDMD	EE
		-------------------------		%	-------------------------		
GP-82	EB	17.54	35.98	6.71	30.21	70.28	6.70
	EH	12.37	39.14	7.50	33.22	61.31	7.50
OS-83	EB	23.59	30.21	3.33	26.42	74.11	3.33
	EH	16.69	33.51	4.65	29.15	62.29	4.65
MT-81	EB	18.09	32.21	3.83	26.99	66.29	2.14
	EH	13.02	37.24	6.94	31.50	57.45	2.05
SD-82	EB	17.90	31.96	3.52	27.47	72.24	2.34
	EH	12.79	36.79	6.06	31.42	60.44	1.75
ST-83	EB	19.32	34.23	4.10	29.17	73.69	2.40
	EH	12.43	38.23	7.15	33.28	59.59	1.58

Stages of development are early boot (EB) and early head (EH).

Table 13. Mean leaf, stem, and inflorescence dry weights, and the leaf-to-stem ratio for 5 *Beckmannia syzigachne* populations harvested at 2 different growth stages.

Population	Growth Stage							
	Early boot				Early head			
	leaf	stem	ratio	inf	leaf	stem	ratio	inf
	-----g------			--g--	-----g------			--g--
MT-81	2.24a	0.80a	2.80b	0.52b	1.71a	2.30b	0.74a	2.27b
SD-82	2.18a	0.80a	2.73b	0.19a	1.81a	1.78a	1.02a	1.86a
GP-82	2.45a	1.70c	1.44a	1.07c	1.64a	2.63c	0.62a	2.94c
OS-83	2.05a	0.61a	3.36c	0.16a	1.73a	1.66a	1.04a	1.72a
ST-83	2.39a	1.30b	1.84a	1.05c	1.78a	2.11b	0.84a	2.41b

Numbers in the same column followed by different letters are significantly different at the 0.01 level.

inflorescence weights within either growth stage. At early boot, the Montana populations (MT-81, SD-82, and OS-83) had significantly less stem and inflorescence tissue and significantly higher leaf-to-stem ratios. MT-81 at early head was not significantly different in stem and inflorescence weights than the South Dakota population (ST-83). Leaf-to-stem ratios were similar for all populations at the early head stage. Therefore, the differences between Montana and South Dakota populations observed at the early boot stage of harvest may have been due to differences in maturity. McMillan (1959) reported later flowering dates for northern populations of _Elymus canadensis_, another cool-season grass, when compared to southern populations in a uniform nursery at Lincoln, Nebraska.

Mean dry matter forage yields from Trial 2 cut at early head in 1986 are presented in Table 14. No significant differences in yield were detected among populations within the individual 1985 cutting treatments. However, there was a significant difference between overall yields with respect to the previous year's cutting treatment. Plots harvested at early boot in 1985 produced significantly less forage in 1986 than plots harvested at early head or for seed. Thus, harvesting _Beckmannia_ prior to heading may prove detrimental to production in subsequent years. Wright et al. (1967) found harvesting bromegrass prior to anthesis reduced forage yields significantly in successive years. Forage quality analyses of the 5 _Beckmannia_ populations harvested in 1986 indicated GP-82 and ST-83 had significantly lower crude protein and significantly

Table 14. Mean dry matter forage yields of 5 *Beckmannia syzigachne* populations harvested at early head in 1986 following differential cutting treatments in 1985.

Population	Growth stage when harvested in 1985		
	Early boot	Early head	seed harvest
	kg/ha		
MT-81	2500	2981	3497
SD-82	2161	2919	2600
GP-82	2847	3318	3067
OS-83	2634	2910	2894
ST-83	2813	4013	3788
Mean	2591a	3228b	3169b

Means followed by different letters are significantly different at 0.01 level.

higher ADF than the other populations (Table 15). This may again reflect the earlier flowering in the South Dakota populations which produces a subsequently earlier reduction in forage quality.

This 2-year study indicated that *B. syzigachne* can be successfully grown in eastern South Dakota as a cultivated forage species. Populations from Montana and South Dakota performed similarly with respect to forage yield and seed production. There was generally increased yield and decreased quality with plant maturity. Higher forage quality was noted in Montana populations at the earlier stage of harvest, however, this may simply be a consequence of a later flowering date. Early harvest of *Beckmannia* may significantly reduce yield in successive harvest years.

Beckmannia syzigachne can be a high yielding, high quality forage in areas where cereal or row-crop farming is unpredictable due to high spring-time moisture. Fall seeding, when moisture levels are more likely to be low, would prevent unpredictably wet areas from being idle during a growing season high in moisture. Stand longevity will depend upon management, but short-term production without dense sod formation is ensured. Rotation from forage to grain production would thus be simplified with regard to tillage operations.

Inflorescence characteristics

Length and width measurements for uni- and biflowered

Table 15. Forage quality of 5 populations of *Beckmannia syzigachne* harvested for forage at early head in 1986.

Population	Forage quality parameters			
	CP	ADF	Lignin	IVDMD
	----------%----------			
MT-81	14.29b	39.57a	5.71c	46.86a
SD-82	13.77b	39.15a	4.76a	48.04b
GP-82	9.17a	42.96b	5.90c	45.84a
OS-83	12.72b	39.65a	5.33b	48.57b
ST-83	10.86a	44.16b	7.17d	42.68a

Numbers in the same column followed by different letters are significantly different at the 0.01 level.

spikelets from 6 *B. syzigachne* populations are presented in Table 16. No significant among population differences were found, but highly significant differences were detected between uni- and biflowered spikelet size. Correspondingly, large spikelets had a significantly higher biflowered percentage than small spikelets (Table 17). Percent biflowered spikelets among the populations ranged from 10 to 76.7 in large spikelets and 0.0 to 6.7 in small spikelets. Population percentages for bulk spikelet samples ranged from 7.5 to 33.8 for MT-80 and KB, respectively. Population KB also had the highest percentage of large and small spikelets that were biflowered.

Table 18 contains mean weights of individual caryopses and spikelet bracts for large and small spikelet fractions. Uni- and biflowered large spikelets had similar spikelet bract and primary caryopsis weights. However, in many cases the primary caryopsis was heavier in biflowered than uniflowered spikelets. The secondary caryopses in the biflowered spikelets weighed approximately 70% of the primary caryopses in all populations. Tibelius and Klinck (1986)similarly found that the primary floret in *Avena sativa* spikelets was larger than the secondary floret. Weights of both caryopses and spikelet bracts in *Beckmannia* were reduced in small spikelets across all populations. However, population MT-81 produced large caryopses in both large and small spikelets and populations DC and BG produced small caryopses in both spikelet fractions. Mean spikelet bract weight of small spikelets was

Table 16. Mean length and width measurements of intact uni- and biflowered spikelets from Beckmannia syzigachne populations grown in the greenhouse.

Population	uniflowered	biflowered
	---mm---	
MT-81	3.1 x 2.0	3.6 x 2.7
MT-80	2.9 x 2.1	3.5 x 2.8
NDC	3.0 x 2.3	3.2 x 2.9
DC	3.0 x 2.4	3.5 x 3.0
KB	3.0 x 2.5	3.2 x 3.0
BG	3.3 x 2.5	3.6 x 2.7

Table 17. Percent biflowered spikelets from greenhouse produced bulk *Beckmannia syzigachne* populations and lots divided into large and small fractions by screening.

Population	n	Percentage biflowered spikelets bulk	n	large	small
		-%-		--------%--------	
MT-80	1200	7.5	60	30.0	2.0
MT-81	600	9.0	30	10.0	0.0
NDC	1200	11.7	60	20.0	2.0
DC	1200	14.0	60	18.3	2.0
KB	600	33.8	30	76.7	6.7
BR	600	8.8	30	20.0	0.0

Table 18. Mean weight of individual caryopses and spikelet bracts from 6 Beckmannia syzigachne populations separated into small and large spikelet fractions by screening bulk populations.

	Uni-flowered			Biflowered			
Population	n	C(p)	SB	n	C(p)	C(s)	SB
Large spikelet fraction							
		----mg----			--------mg--------		
MT-80	58	0.30	0.47	69	0.31	0.20	0.44
MT-81	27	0.38	0.54	12	0.37	0.26	0.56
NDC	32	0.27	0.55	48	0.30	0.20	0.53
DC	37	0.24	0.49	46	0.25	0.18	0.49
BG	18	0.23	0.55	17	0.24	0.19	0.48
KB	25	0.24	0.46	66	0.25	0.20	0.45
Grand mean		0.28	0.50		0.28	0.20	0.48
Small spikelet fraction							
MT-80	113	0.24	0.24				
MT-81	31	0.29	0.25				
NDC	75	0.23	0.27				
DC	60	0.18	0.24				
BG	31	0.19	0.25				
KB	29	0.25	0.29				
Grand mean		0.23	0.25				

C(p) primary caryopsis, C(s) secondary caryopsis, and SB spikelet bract approximately half the spikelet bract weight of the large spikelet fraction.

Analyses of variance indicated significant differences among populations for inflorescence length and spikelet number (Table 19). Population AL-73 had a mean inflorescence length more than 2 times longer than the other populations. AL-73 inflorescences also contained about 4 times as many spikelets as those of the other 3 populations. Chi-square analyses of frequency data for sterile versus fertile and uniflowered versus biflowered spikelets indicated highly significant differences among populations for the two comparisons. Population AL-73 had no biflowered spikelets among the 500 random spikelets dissected for this study. Population ST-83 had the highest sterility rate with 14 % of the spikelets lacking caryopses (Table 19). Regression of spikelet number on inflorescence lengths of the 4 populations indicated a linear trend, with a positive correlation between inflorescence length and spikelet number (r=0.91).

Regression of inflorescence length, spikelet number, caryopsis weight, and spikelet bract weight on latitude indicated positive correlations for inflorescence length and spikelet number and negative correlations for caryopsis and spikelet bract weights (Table 20). Crouch and Vander Kloet (1980) found a significant negative correlation between latitude and seed weight of *Vaccinium* and *Cyanococcus*. *Beckmannia* populations, from south to north, have progressively longer inflorescences and greater numbers of

Table 19. Mean inflorescence length (IL), spikelet number per inflorescence (SN), and percentage of uniflowered, biflowered, and infertile spikelets in 4 _Beckmannia syzigachne_ populations.

Population	n	IL	SN	n	Percent spikelet composition		
					sterile	uni-	bi-
		-mm-			%		
AL-73	10	224b	1017b	500	7.0	93.0	0.0
MT-81	10	104a	251a	500	7.0	69.8	23.2
GP-82	10	93a	161a	500	1.4	62.6	36.0
ST-83	10	95a	174a	500	14.0	80.2	5.8

Numbers in columns followed by a different letter are significantly different at the 0.01 level.

Table 20. Coefficient of determination, slope, linear regression mean square (LRms), and deviation from regression mean square (DLms) for inflorescence length, spikelet number, caryopsis weight, and spikelet bract weight for populations of *Beckmannia syzigachne* regressed on latitude.

Regressable factors	LRms	DLms	b	r^2
Inflorescence length	742808**	1729	6.27	0.92
Spikelet number	8264387**	110414	41.07	0.66
Caryopsis weight	2.653**	0.011	-0.005	0.86
Spikelet bract weight	4.650**	0.052	-0.017	0.70

**, indicates significance at the 0.01 level.

spikelets, but caryopsis and spikelet bract weights are reduced. Primack (1978) similarly found negative correlations between seed weight and seed number / capsule and between seed weight and capsule number / inflorescence among 30 species in the genus *Plantago*. Regression of caryopsis weight on spikelet bract weight indicated a significant linear trend for all populations, with GP-82, MT-81, and ST-83 being positive and AL-73 negative (Table 21). Populations GP-82, MT-81, and ST-83 had larger caryopses when the spikelet bracts were correspondingly large while in population AL-73 there was a negative correlation between spikelet bract weight and caryopsis weight.

Significant differences were found both within and among the 4 populations for weights of spikelet bracts and primary caryopses for both uni- and biflowered spikelets (Table 22). Significant differences in weights were detected between inflorescences within populations for uniflowered spikelet bracts and biflowered primary and secondary caryopses. Population AL-73 had the smallest and ST-83 had the largest spikelet bracts and caryopses (Table 23). Comparisons of spikelet bracts and primary caryopses of biflowered versus uniflowered spikelets revealed that biflowered components were larger in all cases (Table 23).

Variability in inflorescence and spikelet characteristics was detected among *Beckmannia syzigachne* populations by this study. All populations studied, with the exception of the Alaskan population, had some biflowered spikelets in their inflorescences.

Table 21. Coefficient of determination, slope, linear regression mean square (LRms), and deviation from linear regression mean square (DLms) for the regression of caryopsis weight on spikelet bract weight of individual Beckmannia syzigachne populations.

Population	LRms	DLms	b	r^2
AL-73	0.3351**	0.0003	-0.15	0.99
GP-82	0.6192**	0.0003	0.67	0.99
MT-81	1.0122**	0.0009	0.59	0.99
ST-83	1.0929**	0.0022	0.29	0.98

**, indicates significance at the 0.01 level.

Table 22. Mean square from analyses of variance of uni- and biflowered spikelet bracts and primary and secondary caryopses.

		Uniflowered			Biflowered		
Source	df	SB-ms	C(p)-ms	df	SB-ms	C(p)-ms	C(s)-ms
Pop.	3	0.316**	0.047**	1	0.064*	0.045**	0.012
I W Pop	16	0.009**	0.00006	8	0.011	0.022**	0.004**
S W Inf	20	0.0003	0.002	10	0.009	0.00022	0.0002

SB=spikelet bract; C(p)=primary caryopsis; C(s)=secondary caryopsis; Pop. population; I W Pop=inflorescence within population; S W Inf=sample within inflorescence.
*,** indicates significance at the 0.05 and 0.01 levels, respectively.

Table 23. Mean weight of individual spikelet bract and caryopsis components from uni- and biflowered spikelets of *Beckmannia syzigachne* populations.

Population	Uniflowered n	Uniflowered SB	Uniflowered C(p)	Biflowered n	Biflowered SB	Biflowered C(p)	Biflowered C(s)
		-----mg----			---------mg---------		
AL-73	465	0.13	0.18				
MT-81	349	0.37	0.32	116	0.52	0.39	0.24
GP-82	313	0.44	0.25	180	0.64	0.29	0.19
ST-83	401	0.54	0.33	29	0.98	0.51	0.38

SB=spikelet bract; C(p)=primary caryopsis; C(s)=secondary caryopsis.

The biflowered characteristic was more common in the larger spikelets in all populations. Caryopsis and spikelet bract weights for populations were negatively correlated with latitude while inflorescence length and spikelet number were positively correlated. Thus, the Alaskan population had longer inflorescences with more spikelets, but the caryopses and associated spikelet bracts weighed less than those of populations from Montana and South Dakota. Baker (1972) found that mean seed weight decreased with altitude in California mountain flora. He hypothesized that decreased seed size was a reflection of reduced photosynthate due to decreasing length of growing season. Bazzaz and Carlson (1979) found that the photosynthetic contribution of reproductive structures accounted for greater than 50% of the carbohydrate for propagule production in *Ambrosia trifida* L. The smaller caryopsis size of the Alaskan population compared to the more southern Montana and South Dakota populations may thus be a consequence of its adaptation to northern areas with a shorter growing season and its production of smaller spikelet bracts with less photosynthetic capacity.

Space-plant nursery study

The initial nursery of 50 *Beckmannia* plants had a 96% survival the first growing season. Following the first winter, 33 plants remained alive in the nursery. Weed competition the second year was severe and hand weeding was done around the plants.

Following the second winter there were 30 of the original 50 plants still alive. Thus, a 60% survival rate was attained with plants which were left unharvested for 3 years, but faced heavy weed competition the second year. Wynia and Boe (1984) speculated that Beckmannia syzigachne was a short-lived perennial under certain growing conditions.

The larger nursery was established in 1985 to determine clipping effects on survival, seed production, and tillering on an individual plant basis. Table 24 contains information concerning mortality within the nursery overall and with respect to plant size and harvesting treatments. Small plants (20-30 culms) accounted for the largest mortality percentage of those harvested, with no mortality within the plants with the most culms (>51). Plants harvested for forage had a higher mortality rate than plants that remained unharvested.

Mean seed yields of individual plants for 1985 and 1986 are presented in Table 25. Mean seed yield increased in 1986, but the variablity was also greater. Plants harvested for forage in 1985 and seed in 1986 produced greater seed yields than the overall nursery in 1986. Larger seed yields in 1986 may be explained due to the fact that weaker plants in the nursery died and did not contribute to seed yield or because plants were established by that time and transplant shock would not adversely affect plant performance.

Selection of the top and bottom 10% of seed yielders in 1985

Table 24. Mortality of <u>Beckmannia</u> <u>syzigachne</u> plants of different sizes following cutting treatments and overall mortality of the nursery established in 1985.

Number of culms	Mortality	Treatment	Mortality
	---%---		---%---
20-30	35.0	Plants harvested	15.0
40-50	10.0	Plants unharvested	3.5
> 51	0.0	Overall	5.5

Table 25. Mean seed yield harvest of *Beckmannia syzigachne* nursery plants in 1985 and 1986 and those harvested for forage in 1985 and seed in 1986.

Year	n	Seed harvest
		-----g-------
1985	279	20.88 $\pm$ 6.13
1986	291	25.02 $\pm$ 13.30
F85-S86	51	30.07 $\pm$ 13.62

and 1986 and matching the individual plant numbers between lists revealed some interesting relationships (Table 26). Two plants yielded high in both years; four yielded low in both years; and seven changed from high to low or vice versa. This indicates that there is little consistency in seed production within individual plants across years. The interannual correlation (r=0.34) calculated using total 1985 and 1986 seed yields from individual plants supports the idea that seed yield is inconsistent. Coefficients of determination for the regression of seed yield on culm number were 0.97 and 0.88 for 1985 and 1986, respectively (Table 27). Thus, a high percentage of the difference among plants for seed yield can be attributed to differences in number of flowering culms. Which is also a reflection of plant size and vigor. The smaller change in seed yield in 1986 with change in culm number may be due to mortality in the smaller plants with lower culm numbers.

It seems that variation in growth habit of Beckmannia syzigachne will depend on its utilization and initial vigor of the plant. A vigorous individual which is used for seed production may live a number of growing seasons. A less vigorous individual harvested for forage at a juvenile stage may have an annual growth habit.

Table 26. Percentage of individual *Beckmannia syzigachne* plants from high and low seed yielding groups which changed from one group to another or remained in the same group.

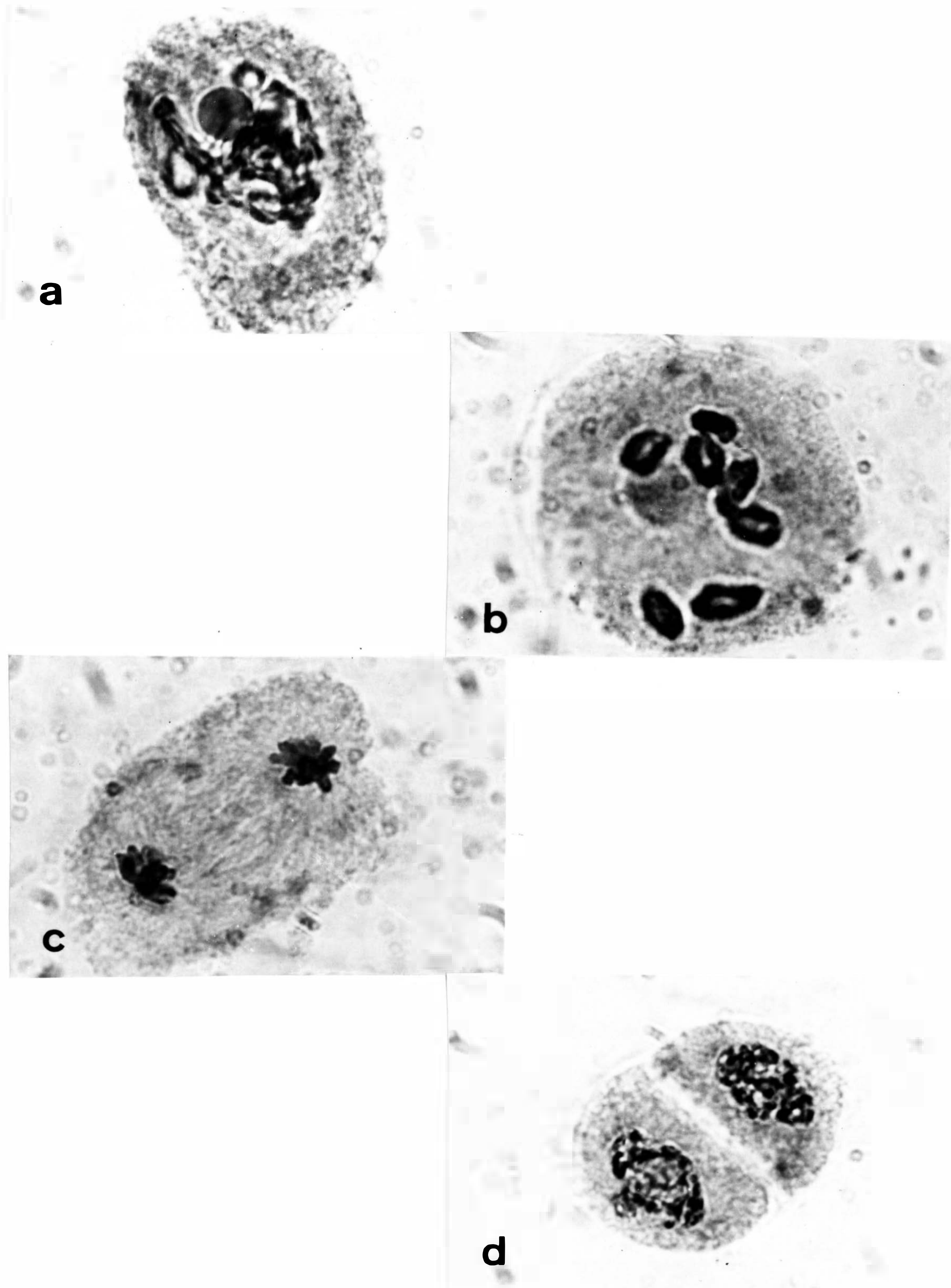
Group year	percentage
High 85-High 86	6.0
High 85-Low 86	12.0
Low 85-Low 86	12.0
Low 85-High 86	9.0

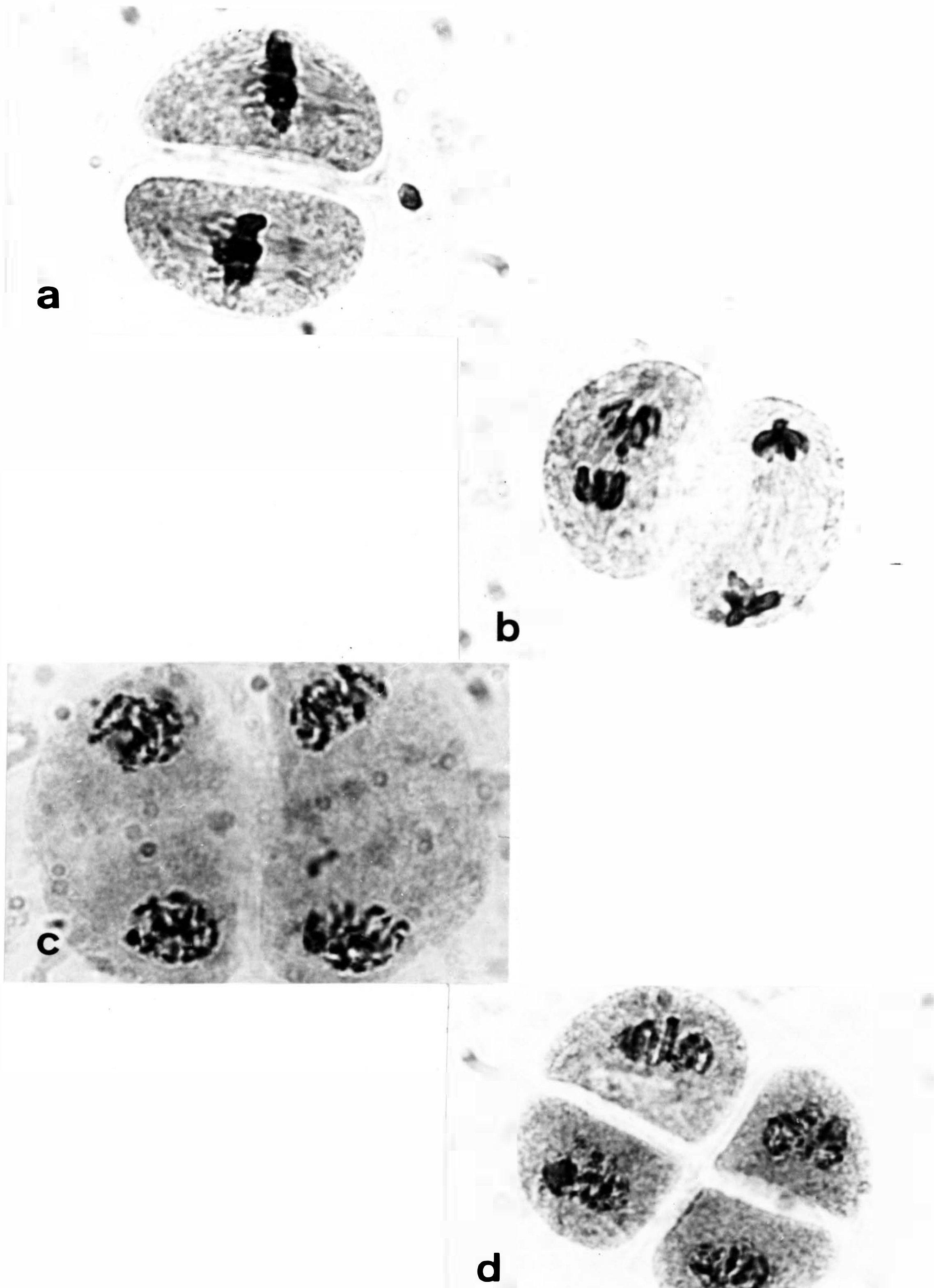
Table 27. Coefficients of determination and slopes for the regression of seed yield on culm number of *Beckmannia syzigachne* nursery plants in 1985 and 1986.

Year harvested	n	b	r^2
1985	278	0.57	0.97
1986	291	0.23	0.88

Chromosome observations

No chromosome abnormalities were observed in the seven populations investigated. Photomicrographs of normal meiosis stages of _Beckmannia_ are presented in Figures 1 and 2. Diakinesis (Fig 1b) provided the opportunity to count chromosome pairs with minimal interference. All populations contained 2n=14 or 7 chromosome pairs. This is the most commonly cited number for both _Beckmannia syzigachne_ and _B. erucaeformis_ (Nielsen and Humphrey 1937 and Reeder 1953). However, there has been a report in the Russian literature of a tetraploid (2n=28) population (Zhukova and Petrovskii 1976). Ploidy differences were not observed in any of the populations studied.


a
b
c
d


a
b
c
d

Conclusions

This research was concerned with the agroecological evaluation of several Beckmannia syzigachne populations from South Dakota, Montana, and Alaska. The major findings of this study are:

1) Percentage and rate of germination of all populations were heighest using 15-30 and 20-30 C alternating temperature regimes.

2) Percentage and rate of germination of the Alaska population were significantly better than South Dakota and Montana populations at constant temperatures.

3) Forage production and quality of South Dakota and Montana populations were similar.

4) Harvest of forage when the plants were in the boot stage compared to early head and later stages tended to reduced forage yield in subsequent years.

5) Individual space-plants were maintained in a nursery for three years, indicating a potential for existence as a short-lived perennial in certain situations.

6) Mortality of space-plants harvested for forage was greater when culm numbers were small.

7) South Dakota and Montana populations consistently produced biflowered spikelets, but none were detected in the Alaska population.

8) Caryopsis and spikelet bract weights for populations were

negatively correlated with latitude while inflorescence length and spikelet number were positively correlated.

9) Cytological observations of pollen mother cells indicated a diploid condition in all populations.

Beckmannia syzigachne has no complex germination requirements and can be established by late fall dormant seedings in eastern South Dakota. High seed production along with good forage yield and quality are indicated. Stand persistence and longevity is dependent on time of harvest and management. Thus, as a potential cultivated forage species this grass has considerable promise. _Beckmannia_ may also offer promise in wetland habitat restoration and improvement for waterfowl species.

Future research may concentrate on utilization of _Beckmannia erucaeformis_ as forage or for crossing with _B. syzigachne_. Hybrid _Beckmannia_ may be possible since both species are diploids. Spikelets and caryopses of _Beckmannia_ should be tested for nutrients and food value. They have been described as excellent food for dabbling ducks and have been used as human food in American Indian and Japanese cultures.

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Table A1. Weight of 25-caryopses lots of three *Beckmannia syzigachne* populations produced in the greenhouse.

GP-82	MT-81	AL-73
	mg	
6.9	8.9	4.8
7.1	9.2	4.9
6.8	8.0	4.9
6.6	8.5	4.8
6.6	8.7	4.9
6.7	8.5	5.0
6.7	8.9	4.8
6.8	8.9	5.1
6.6	8.6	5.2
6.8	9.0	4.8
8.0	9.0	4.8
6.6	9.3	4.8
7.4	8.9	4.8
6.9	9.0	5.1
6.7	9.0	4.9
7.2	8.7	5.0
7.3	9.0	5.1
7.4	8.9	4.7
6.7	8.5	5.1
6.5	9.3	4.7

Table A2. Percent germination of freshly harvested <u>Beckmannia</u> caryopses at three constant and two alternating temperature regimes.

Temperature	Days after planting	GP-82	Populations MT-81	AL-73
		%		
15-30C	3	6	3	80
	6	57	56	90
	9	83	86	90
	12	89	87	90
	14	89	91	90
20-30C	3	3	9	80
	6	43	73	89
	9	60	83	89
	12	68	87	90
	14	71	91	90
15C	3	0	0	0
	6	4	11	24
	9	11	19	63
	12	19	29	80
	14	25	33	81
20C	3	1	0	38
	6	1	2	61
	9	2	2	71
	12	4	2	72
	14	4	2	72
25C	3	0	0	68
	6	3	0	84
	9	4	3	86
	12	4	3	86
	14	4	4	86

Table A3. Percent of Beckmannia seedlings separated into distinct height classes over time when grown under different temperature regimes.

Temp.	Days after planting	@ GP-82 1	2	3	MT-81 1	2	3	AL-73 1	2	3
		%								
15-30	3	6	0	0	3	0	0	80	0	0
	6	41	10	6	47	9	0	1	22	67
	9	19	24	40	38	23	25	0	1	89
	12	6	11	72	7	13	67	0	0	90
	14	0	7	82	2	10	79	0	0	90
20-30	3	9	0	0	9	0	0	68	0	0
	6	19	12	12	50	14	9	5	10	74
	9	13	14	33	17	17	51	1	4	85
	12	5	10	53	9	6	73	1	1	88
	14	2	9	60	3	6	82	0	1	89
15	3	0	0	0	0	0	0	0	0	0
	6	4	0	0	10	0	0	24	0	0
	9	9	2	0	17	2	0	46	17	0
	12	12	3	4	14	7	8	33	20	27
	14	13	6	6	11	6	15	6	34	41
20	3	1	0	0	0	0	0	38	0	0
	6	0	0	1	2	0	0	16	10	35
	9	0	1	1	0	1	1	5	10	56
	12	2	0	2	0	1	1	2	5	65
	14	0	2	2	0	1	1	0	4	68
25	3	2	0	0	0	0	0	54	14	0
	6	1	0	2	0	0	0	6	19	59
	9	1	0	3	1	2	0	3	7	76
	12	0	1	3	0	1	2	0	3	83
	14	0	1	3	1	0	3	0	2	84

@ Height classes are: 1 (0.10-0.50), 2 (0.51-1.00), and 3 (>1.00) centimeter, respectively.

Table A4. Total, wet sample, and dry sample weights of forage harvested on 19 June 1985 from the 1984 <u>Beckmannia</u> yield trial.

Plot	Population	Total	Wet	Dry
		--kg--	--------g----------	
101	MT-81	4.3	316	48
102	GP-82	4.9	251	45
103	OS-83	4.0	218	38
104	SD-82	4.3	268	50
105	ST-83	3.6	224	41
201	ST-83	4.7	347	59
202	SD-82	4.3	298	51
203	OS-83	3.7	283	50
204	MT-81	4.1	238	40
205	GP-82	4.4	228	39
301	OS-83	4.5	231	40
302	ST-83	5.3	274	45
303	SD-82	4.3	296	55
304	GP-82	5.4	208	36
305	MT-81	5.1	240	44
401	OS-83	2.5	244	47
402	SD-82	3.7	227	41
403	ST-83	2.8	214	38
404	GP-82	4.8	255	48
405	MT-81	3.7	237	44

Table A5. Total, wet sample, and dry sample weights of forage harvested on 2 July 1985 from the 1984 Beckmannia yield trial.

Plot	Population	Total	Wet	Dry
		--kg--	--------g----------	
101	MT-81	5.1	174	39
102	GP-82	4.7	212	53
103	OS-83	5.9	191	41
104	SD-82	6.0	206	43
105	ST-83	5.1	232	69
201	ST-83	4.1	248	79
202	SD-82	5.0	225	45
203	OS-83	4.6	245	67
204	MT-81	5.1	269	66
205	GP-82	5.1	231	63
301	OS-83	4.2	265	69
302	ST-83	5.0	190	55
303	SD-82	5.0	207	54
304	GP-82	4.9	243	67
305	MT-81	5.3	249	64
401	OS-83	4.3	190	55
402	SD-82	4.3	226	54
403	ST-83	4.6	312	83
404	GP-82	5.1	259	68
405	MT-81	4.6	201	49

Table A6. Total plot wet and dry weights of forage harvested on 12 June 1986 from the 1984 *Beckmannia* yield trial.

Plot	Pop.	Treatment @	Wet	Dry
			--------g----------	
101	MT-81	1st	902	265
101		2nd	1184	305
101		SH	2005	540
102	GP-82	1st	1204	375
102		2nd	1362	420
102		SH	1248	393
103	OS-83	1st	615	185
103		2nd	845	225
103		SH	1318	340
104	SD-82	1st	630	190
104		2nd	914	255
104		SH	1247	335
105	ST-83	1st	350	145
105		2nd	627	220
105		SH	1379	455
201	ST-83	1st	1735	540
201		2nd	2320	695
201		SH	1695	515
202	SD-82	1st	1108	287
202		2nd	1880	485
202		SH	1237	340
203	OS-83	1st	1037	348
203		2nd	1237	348
203		SH	944	296
204	MT-81	1st	1219	325
204		2nd	1334	380
204		SH	1046	325
205	GP-32	1st	602	220
205		2nd	860	285
205		SH	1116	350
301	OS-83	1st	1375	375
301		2nd	1655	430
301		SH	1112	315
302	ST-83	1st	882	315
302		2nd	1608	525
302		SH	1093	400
303	SD-82	1st	1062	280
303		2nd	870	255
303		SH	722	215
304	GP-82	1st	1170	365
304		2nd	1163	375
304		SH	904	315

Table A6. (Cont.)

305	MT-81	1st	1007	275
305		2nd	1264	330
305		SH	1300	355
401	OS-83	1st	1285	335
401		2nd	1005	295
401		SH	1075	340
402	SD-82	1st	695	207
402		2nd	1055	307
402		SH	860	270
403	ST-83	1st	690	255
403		2nd	1032	350
403		SH	875	320
404	GP-82	1st	980	310
404		2nd	1305	400
404		SH	992	310
405	MT-81	1st	872	250
405		2nd	1195	315
405		SH	1140	340

@ Treatment indicates first cut, second cut, and seed harvest in 1985.

Table A7. Inflorescence length and spikelet number of four *Beckmannia* populations produced in the greenhouse.

Population	Inflorescence number	Inflorescence length	Spikelet number
		--mm--	
AL-73	1	128	680
	2	254	1276
	3	227	846
	4	213	1374
	5	190	892
	6	230	757
	7	281	843
	8	208	1593
	9	239	778
	10	267	1133
GP-82	1	85	108
	2	77	106
	3	96	232
	4	105	183
	5	100	174
	6	100	134
	7	92	174
	8	90	149
	9	88	141
	10	99	207
MT-81	1	94	263
	2	122	339
	3	134	311
	4	91	208
	5	85	180
	6	103	252
	7	100	295
	8	115	233
	9	94	176
	10	100	255
ST-83	1	129	278
	2	108	224
	3	71	104
	4	100	141
	5	76	133
	6	79	173
	7	90	119
	8	104	161
	9	102	230
	10	95	174